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THE EFFECT OF HYDROCYANIC ACID GAS UPON GRAINS AND OTHER SEEDS.

C. O. TOWNSEND.

(WITH SIX FIGURES)

INTRODUCTION.

THE experiments which form the basis of this paper were undertaken more than two years ago for the purpose of determining the effect of hydrocyanic acid gas upon the germination of seeds. The necessity for the work arose from the rapidly increasing use of this gas in the destruction of insect pests infesting stored grains and other seeds. Since these experiments were begun a number of the largest flour mills in this country and Canada have been fumigated for the destruction of insects without removing the thousands of bushels of grain stored in the mills, and likewise numerous barns and granaries filled with grain have been fumigated for the same purpose. Since the grain thus fumigated may be used either for seed or for food, it is important to know whether or not the germinating quality of the grain has been injured and whether grain thus treated would be injurious for food. A preliminary account of the experiment in regard to germination of seeds after treatment with hydrocyanic acid gas was read before the Botanical Section of the A. A. A. S. at the Columbus meeting and subsequently published.[1]

The use of hydrocyanic acid gas for fumigating purposes is of comparatively recent origin, having been introduced by the U. S. Department of Agriculture, Division of Entomology, in 1886, for the fumigation of orange trees. It was first used for the fumigation of greenhouses by Dr. A. F. Woods,[2] Director of the

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[1] TOWNSEND: "The effect of hydrocyanic acid gas upon the germination of seeds." Sci. Amer. Suppl., no. 1248, 2 D. 1899.

[2] WOODS: The variable effects of hydrocyanic acid gas on plants and animals. Rep. Soc. Plant Morph. and Physiol., Am. Nat. 1899.

Division of Vegetable Physiology and Pathology, and even before it was used for fumigating purposes its effect in solution was determined by Dr. Loew.[3]

This gas has now come into universal use not only for the fumigation of trees and grains as above indicated, but also for the fumigation of greenhouses,[4] nursery stock, and even orchard trees of all kinds.[5]

The object of the writer in performing these experiments, the results of which are herein recorded, has been simply to determine whether or not hydrocyanic acid gas has any injurious effect upon grains or other seeds; and, if so, under what conditions and to what extent the injury is produced. Hence this paper is merely preliminary to the more minute study of the subject, since it deals only with the cause and effect, while the nature of the action of the poison upon the several parts of the seed still remains for further investigation.

In general the methods employed in these experiments have consisted simply in placing the seeds to be tested in air tight chambers in which hydrocyanic acid gas is generated. In the first experiments the chambers consisted of air tight boxes of several cubic feet capacity, used primarily for the fumigation of nursery stock. These boxes were open on one side, the open side being placed next the ground, which was first made perfectly smooth and level. In experimenting with these boxes, they were raised slightly on one edge, the material to be fumigated was placed under them, and at the moment the hydrocyanic acid gas was generated the boxes were lowered and sand quickly pressed around the edges next the ground, making them practically gas-tight. In these as in the subsequent experiments the gas was generated by placing cyanid of potassium (KCN) in dilute sulfuric acid (H_2SO_4), the result of the chemical action being the evolution of hydrocyanic acid gas (HCN) according to the following chemical equation: $2KCN + H_2SO_4 = 2HCN + K_2SO_4$. In the later experiments bell jars were used having a capacity of approximately one third of a cubic foot each (*fig. 1*). The bell jars were provided with ground glass stoppers, and were placed on ground glass plates, the edges being sealed with oil to prevent the escape of the gas. Having prepared the seeds in the manner desired, they were placed on the ground glass plate, and in a small beaker directly in the center of the plate was the dilute sulfuric acid, so that when the bell jar was placed in position the beaker containing the sulfuric acid was exactly below the glass stopper in the bell jar. The potassium cyanid was carefully weighed and wrapped in fine tissue paper. A piece of twine, just equal in length to the distance from the lower surface of the glass stopper in the bell jar to the bottom of the beaker containing the sulfuric acid, was tied to a package containing the desired weight of potassium cyanid, and the other end of the string was fastened by means of soft paraffin to the lower surface of the glass stopper of the bell jar. When everything was ready to begin the experiment the package of potassium cyanid attached to the string was lowered through the opening in the top of the bell jar, and just at the instant when this package came into contact with the dilute sulfuric acid the ground glass stopper fell into place and thus hermetically sealed the jar. By this means it was possible to keep the seeds for any required length of time in an atmosphere of hydrocyanic acid gas of desired strength. When the bell jars were opened, even after several months, the characteristic odor resembling peach kernels could be detected, showing that the gas had neither escaped nor been absorbed, although in at least some of the experiments a portion of the gas was probably absorbed, since it has a strong affinity for moisture. It should be borne in mind that both the potassium cyanid and the hydrocyanic acid gas are deadly poisons and great care should be exercised in using them. Potassium cyanid is a white solid and is on the market in several forms. It should be purchased for use in the lump form usually known as 98 per cent. cyanid of

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[3] LOEW: Natur. System der Giftworkung. Bull. Imp. Univ. Coll. Agr. 1: 34. 1893. The poisonous action of dicyanogen.

[4] WOODS and DORSETT: The use of hydrocyanic acid gas for fumigating greenhouses and cold frames. Circ. no. 37. Ser. 2, U. S. Dept. Agr., Div. Ent.

[5] JOHNSON: Report on the San José scale. Bull. 57, Md. Agr. Exper. Station. 1897.

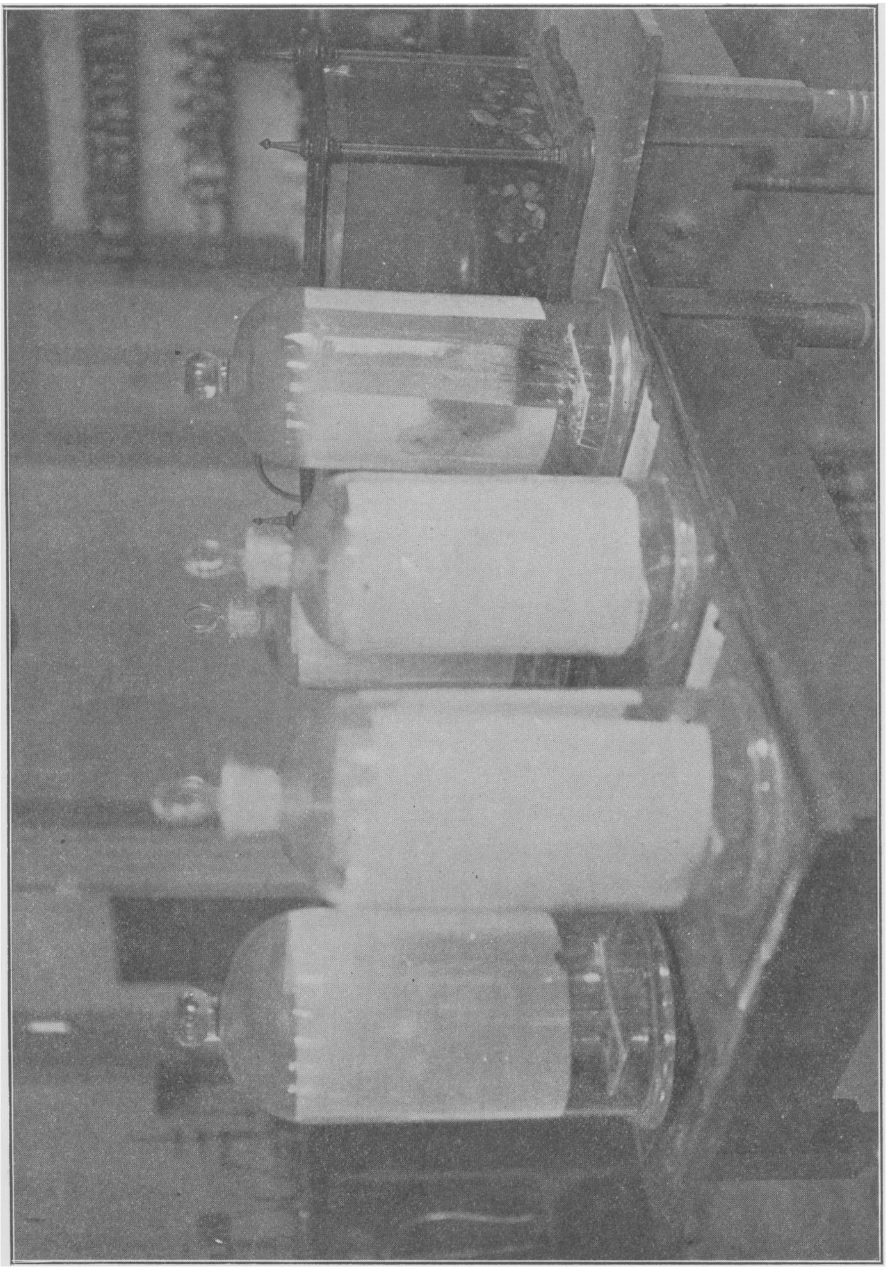

FIG. 1.—Bell jars in which the effect of hydrocyanic acid gas upon the germination of seeds is being determined.

potassium, and should be kept in air tight cans or jars until ready for use.

If the seeds were to be treated in the dry state, no moisture was added except what was used to dilute the acid, and this consisted of only a few cubic centimeters of water. On the other hand, if damp seeds were to be treated with hydrocyanic acid gas, they were first soaked for the desired length of time in water, and then placed on moist filter paper under the bell jar, which was lined with damp filter paper, thus providing for the seeds a moist atmosphere favorable for their germination. All the chambers, whether damp or dry, were kept in the general laboratory where a pretty constant temperature of about 18° C. was maintained. Further details in regard to methods can best be made clear by referring to the accompanying tables and their descriptions. The materials used in these experiments consisted for the most part of corn, wheat, beans, and clover seed. Occasionally other seeds were used in addition to those mentioned, but these four were carried through all the experiments and may be considered as fairly representing the seeds of monocotyledonous and dicotyledonous plants. Under certain conditions some of the seeds used seemed to be more sensitive to the treatment to which they were subjected than the others, but in general the behavior of the seeds under the conditions used was similar for all seeds under identical conditions, the difference being simply a matter of degree. In other words, if the effect of the treatment was to accelerate germination all the seeds germinated more quickly than under normal conditions, whereas if the effect of the treatment was to retard germination then all germinated less readily than under normal conditions, although all seeds of the same kind did not germinate at the same moment.

The strength of hydrocyanic acid gas used in these experiments is stated in terms of the weight per cubic feet of space to be fumigated of the cyanid of potassium used in generating the gas. In fumigating nursery stock for the destruction of insect pests, as well as for fumigating mills, barns, etc., 0.25^{gm} of cyanid of potassium is used for each cubic foot of space to be fumigated.[6]

In these experiments the strength of the gas varied from 0.003^{gm} per cubic foot to 1.45^{gm} per cubic foot. While in the first experiments the object was simply to determine whether or not the ordinary strength of the gas used in fumigation would be harmful to the grain or other seeds, in the later experiments an effort was made to determine the maximum and minimum strength of gas that the seeds could resist under the several conditions employed. It should be noted that time is an important factor in these experiments. Nursery stock may be fumigated in thirty minutes, so that all insect life will be destroyed; but in fumigating buildings in which large bulks of grain are stored time must be allowed for the gas to penetrate the mass of grain and thus reach the insects that may be scattered through it. While time is being given for the gas to penetrate the bulk of grain, the grain on the surface of the bulk is exposed to the influence of the gas from the time it is generated. Hence an effort was made to determine the maximum and minimum time required for the grains to respond to the influence of the various strengths of gas used under the several conditions employed, and with this point in view the exposures varied from one hour to one year.

EXPERIMENTS WITH DRY SEEDS.

Trial experiments.—In the first experiments dry seeds were placed in shallow dishes and exposed for one hour to charges of gas varying in strength from 0.25^{gm} to 1.45^{gm} of potassium cyanid per cubic foot. Only a thin layer of seeds was placed in each dish, so that the gas came directly into contact with each seed. At the end of one hour the seeds were taken from the fumigating chamber and placed in hydrant water for twenty-four hours. At the expiration of this time they were spread upon moist filter paper in damp chambers and kept at ordinary room temperature of about 18° C. In this, as in all the other tests, control experiments were used in which the seeds were treated in precisely the same manner and kept under exactly the same conditions as in the subsequent experiments, except that they were not subjected to the influence of the gas.

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[6] JOHNSON, *loc. cit.*

The first line in each table expresses the result of the control experiments for that particular set of experiments, so that in whatever manner the seeds under examination behaved it was clear that the variation in behavior from the seeds in the control experiments resulted entirely from the effect of the hydrocyanic acid gas.

In all cases it was found that the seeds that had been subjected to the gas for one hour germinated just as readily as if they had not been in the gas at all. Hence it may be concluded that perfectly dry seeds may be subjected for a short time to the influence of gas six times as strong as that ordinarily used in fumigation without any appreciable injury to the germinating quality of the seed.

TABLE I.

Dry seeds subjected to the influence of hydrocyanic acid gas, then soaked and placed under conditions favorable for germination; temperature 18° C.

Amount of KCN per cubic foot	Time of exposure to gas	Time of soaking	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.00 . . .	1 hour	24 hours	24 hours	100	normal
0.25 . . .	1 "	24 "	24 "	100	"
0.45 . . .	1 "	24 "	24 "	100	"
0.60 . . .	1 "	24 "	24 "	100	"
0.75 . . .	1 "	24 "	24 "	100	"
1.00 . . .	1 "	24 "	24 "	100	"
1.25 . . .	1 "	24 "	24 "	100	"
1.45 . . .	1 "	24 "	24 "	100	"

Subsequent experiments.—In the trial experiments the seeds were subjected to the influence of hydrocyanic acid gas for one hour only. In order to determine the influence of this gas upon seeds exposed for a long time, subsequent experiments with dry seeds were undertaken. The seeds were placed in shallow dishes which were covered by bell jars, made air tight, and the gas generated in the manner described. Control experiments were started at the same time, in which the seeds were covered by bell jars under the same conditions as in the experiments, with the exception that no KCN was placed in the dilute sulfuric acid. The results are best expressed in the following table:

TABLE II.

Dry seeds treated with hydrocyanic acid gas for long periods of time: temperature throughout about 18° C.

Amount of KCN per cubic foot	Time of exposure to gas	Time of soaking	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000 . . .	0	24 hours	24 hours	100	normal
0.333 . . .	15 days	24 "	12 "	100	accelerated
1.000 . . .	15 "	24 "	7 "	100	accelerated
0.333 . . .	60 "	24 "	9 "	100	accelerated
1.000 . . .	60 "	24 "	14 "	100	slightly retarded
0.333 . . .	153 "	24 "	30 "	75	slightly retarded
1.000 . . .	153 "	24 "	36 "	60	greatly retarded
0.333 . . .	240 "	24 "	76 "	50	retarded half
1.000 . . .	240 "	24 "	96 "	10	very slight
0.333 . . .	365 "	24 "	240 "	20	none
1.000 . . .	365 "	24 "	no germination	0	

From the foregoing table it will be seen that the seeds were constantly under the influence of the gas for from fifteen days to one year. The strength of the gas was constant in each jar, *i. e.*, it did not vary except possibly by the absorption of a small quantity of the gas into the seeds and into the few cubic centimeters of dilute acid used in generating the gas. It is surprising that the seeds should germinate more readily after they had been exposed to the gas for a few days, although the same phenomenon was observed in the action of ether upon the germination of seeds.[7]

At the expiration of sixty days the acceleration of germination had passed its maximum, and shortly after began to be retarded, until at the end of two hundred and forty days germination practically ceased for those seeds that were exposed to the gas from one gram of KCN per cubic foot (*fig. 2, c*). The seeds that were in the weaker charge of gas continued to germinate about four months longer, but that was evidently the limit, as only a few of the seeds germinated very feebly at the expiration of that time (*fig. 3, b*). Not only was the germination hastened, but the subsequent growth was likewise accelerated for a limited time. Although the subsequent growth of seedlings was in some instances very marked, being almost double that of the normal, this acceleration was of short duration, rarely lasting more than one week, and then gradually resuming the normal rate of growth. Hence the acceleration is probably not of sufficient duration to be of any commercial value.

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[7] TOWNSEND: The influence of ether upon the germination of seeds and spores. BOT. GAZ. **27**: 458. 1899.

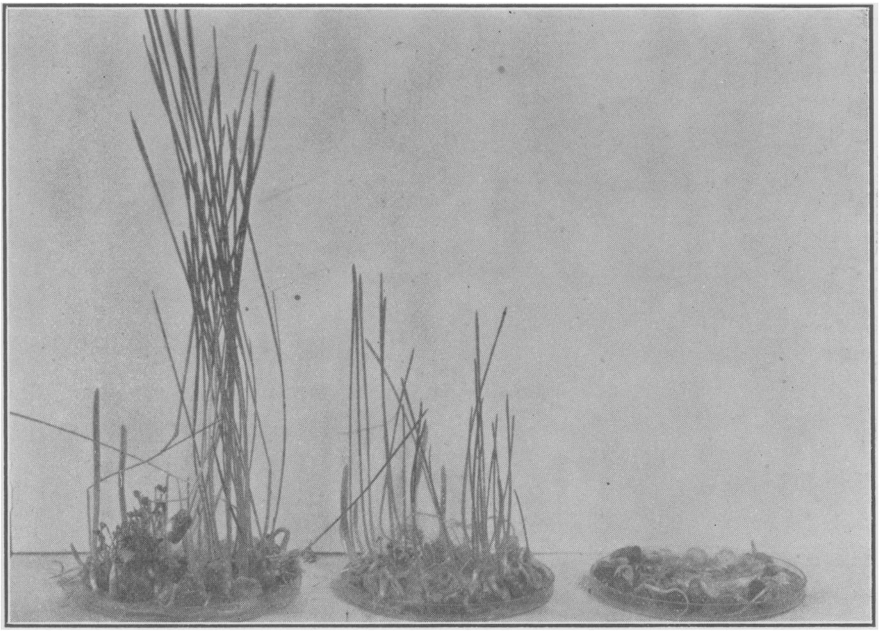

FIG. 2.—*a*, control; *b*, from seeds that were eight months in gas from 0.333^{gm} KCN per cubic foot; *c*, seeds that were eight months in gas from 1^{gm} KCN per cubic foot.

It appears from these experiments that dry seeds may be treated with hydrocyanic acid gas continuously for several weeks without reducing the percentage of germination or interfering seriously with the subsequent growth of the seedlings. It is clear, however, that the gas has a marked influence upon dry seeds. The extent of the influence depends upon the amount of gas per cubic foot and upon the time the seeds are subjected to its influence. After sixty days the percentage of germination was gradually reduced, and the subsequent growth of seedlings was likewise retarded. The greater reduction in the percentage of germination, as well as in retardation of growth, depended upon the length of time of exposure to the gas and upon the amount of gas present. At the end of eight months the seeds in the gas from one gram of KCN had practically lost their ability to germinate, since only one in ten was capable of even slight germination, and those were too feeble for subsequent growth (*fig. 2, c*). If the gas was generated from only one third of a gram of KCN per cubic foot, the seeds retained their ability to

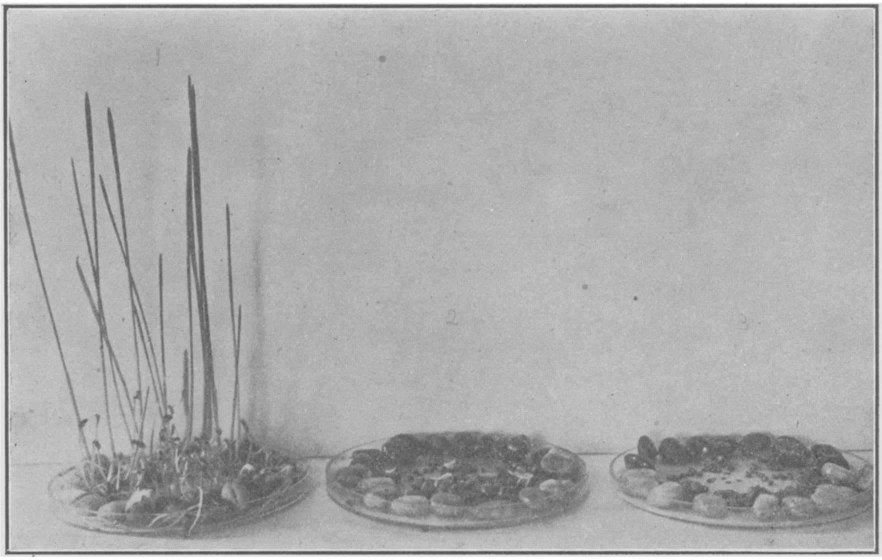

FIG. 3.—*a*, control; *b*, seeds that were one year in gas from 0.333^{gm} KCN per cubic foot; *c*, seeds that were one year in gas from 1^{gm} KCN per cubic foot.

germinate four months longer, or one year from the beginning of the experiment (*fig. 3, b*). In general it may be stated that the length of time that dry seeds retain their ability to germinate varies inversely with the strength of gas to which the seeds are subjected. Likewise the converse of this is true, viz., that the strength of gas that will prevent seeds from germinating varies inversely with the time that the seeds are subjected to the influence of the gas. These rules are stated only for the seeds that are subjected to the gas under the foregoing conditions, and will not apply with certainty to seeds under other conditions. It should be stated in this connection that the seeds in the control jar did not germinate quite normally either in percentage or point of time at the end of twelve months (*fig. 3, a*). To what this slight variation was due has not yet been determined, but it does not seem probable that it was sufficient to affect the results in the jars containing the gas. Seeds from the original packages not inclosed in a jar germinated normally, *i. e.*, 100 per cent. in twenty-four hours.

EXPERIMENTS WITH MOIST SEEDS.

Since it may sometimes be necessary to fumigate grain or other seeds while in a moist condition, experiments were undertaken for the purpose of determining what effect hydrocyanic acid gas would have upon seeds that had been soaked for a longer or shorter time in water. After soaking the seeds the following conditions were observed, viz., the damp seeds were left to germinate in the gas which was of different strengths in different jars; they were then placed for a time in the gas of different strengths and then removed to a gas free atmosphere.

Damp seeds allowed to remain in hydrocyanic acid gas.— By referring to tables III, IV, and V it will be seen that the seeds were soaked for different lengths of time, and that they were subjected to atmospheres of gas of different strengths.

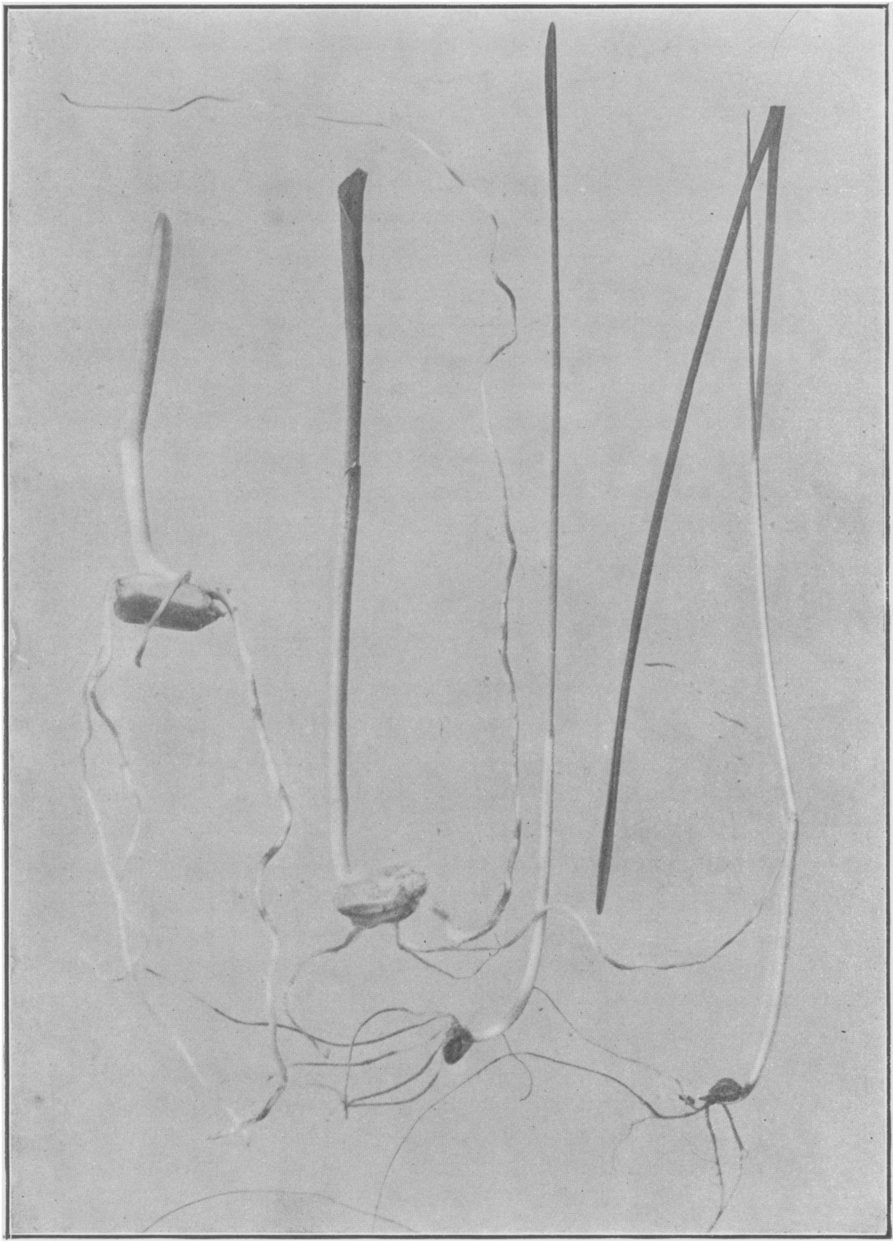

FIG. 4.—Corn and wheat seedlings. The larger one in each case is normal, while the smaller ones were from seeds treated eight months with gas from 0.333^{gm} KCN per cubic foot.

TABLE III.

Germination of damp seeds and subsequent growth of resulting seedlings in hydrocyanic acid gas; temperature throughout about 18° C.

Amount of KCN per cubic foot	Time of soaking	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000	24 hours	24 hours	100	normal
0.003	24 "	168 "	90	very slow
0.010	24 "	no germination	0	. . . .
0.050	24 "	no germination	0	. . . .
0.060	24 "	no germination	0	. . . .
0.075	24 "	no germination	0	. . . .

It will be observed in table III that the amount of KCN used varied from 0.003 to 0.075^{gm} per cubic foot, but that no germination took place if more than 0.003^{gm} was used, and indeed in this strength of gas germination was delayed for six days. Other quantities of KCN between 0.003 and 0.010^{gm} were used, but the seeds seemed to be unable to germinate in any charge stronger than 0.003^{gm} per cubic foot. The subsequent growth of the seedlings in this very small amount of hydrocyanic acid gas was very slight, and did not exceed two inches in ten days, in some instances the growth being only a fraction of an inch.

TABLE IV.

Same as table III, except that the seeds were soaked for a shorter time before placing in the gas.

Amount of KCN per cubic foot	Time of soaking	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000	12 hours	24 hours	100	normal
0.003	12 "	36 "	80	slight
0.010	12 "	36 "	40	very slight
0.050	12 "	40 "	20	none
0.060	12 "	no germination	0	. . . .
0.075	12 "	" "	0	. . . .

In the experiments recorded in table IV the seeds were soaked only twelve hours, but the control seeds germinated in practically the same time as in the preceding case where the seeds were soaked for twenty-four hours. It is also important to note that the small charge of only 0.003^{gm} of KCN retarded the germination but a few hours as compared with the retardation produced by the same charge of gas when the seeds were soaked for twenty-four hours. It is likewise a noteworthy fact that when the seeds were soaked but twelve hours they were much more resistant to the influence of hydrocyanic acid gas, as evidenced by the fact that at least a few of the seeds were able to germinate in as much as 0.050^{gm} of KCN per cubic foot. The subsequent behavior of the seedlings was the same as in the preceding case, *i. e.*, there was little or no growth after the plant escaped from the seed coats. In general it was found that the shorter time the seeds were soaked the more resistant they were to the influence of the gas.

TABLE V.

Same as table III, except that the seeds were soaked for a longer time before placing in the gas.

Amount of KCN per cubic foot	Time of soaking	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000	36 hours	20 hours	100	normal
0.003	36 "	48 "	60	slight
0.010	36 "	no germination	0	. . . .
0.050	36 "	" "	0	. . . .
0.060	36 "	" "	0	. . . .
0.075	36 "	" "	0	. . . .

In these experiments it will be seen that the extra amount of soaking caused the seeds to germinate more readily than they would have done had they been soaked but twenty-four hours, both in the case of the control experiments and in the experiments in which but 0.003^{gm} of KCN was used. However, the seeds did not germinate as readily as they did when soaked but twelve hours, nor was the percentage of germination so high as in either of the preceding cases. It is probable that the germination took place more quickly than in the experiments recorded in table III, because the seeds were more advanced before they were removed from the water and placed in the gas. In all cases the seeds were extremely sensitive and made but very slight growth after breaking through the seed coats. Leaving out of account the advance that the seeds made toward germination while they were in the water and before placing them in the gas, it appears that their sensitiveness increased with the length of time that they were allowed to soak. This is to be expected since hydrocyanic acid gas has a strong affinity for moisture and is readily absorbed by water.

Seeds soaked for a definite time in water, placed for a given time in hydrocyanic acid gas, and then removed to a gas free atmosphere.— When it was observed that the seeds which had been soaked and then placed in hydrocyanic acid gas germinated more slowly than under normal conditions, it was apparent that the seeds were being held in a dormant state for a longer or shorter time depending upon the length of time the seeds were soaked, upon the strength of gas used, and upon the length of time that the seeds were allowed to remain in the gas. In order to get more definite information in regard to this point, experiments were undertaken whose results are recorded in tables VI and VII.

TABLE VI.

Germination of seeds and subsequent growth of seedlings after soaking in water, then placing for a definite time in hydrocyanic acid gas, and then removing to a gas free atmosphere; temperature 18° C.

Amount of KCN per cubic foot	Time of soaking	Time of exposure to gas	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000 . . .	24 hours	0	24 hours	100	normal
0.003 . . .	24 "	168 hours	already germ.	90	slow
0.010 . . .	24 "	168 "	168 hours	50	very slow
0.050 . . .	24 "	168 "	336 "	20	barely started
0.c60 . . .	24 "	168 "	no germination	0	....
0.120 . . .	24 "	168 "	" "	0	....

As shown in table III, seeds that have been soaked for twenty-four hours and then left for seven days or 168 hours in an atmosphere containing gas from 0.003^{gm} of KCN per cubic feet were able at the end of that time to germinate without removing from the gas, while seeds subjected to a stronger charge of gas were unable to germinate in the gas. Hence the experiments as recorded in table VI were undertaken. In these experiments the seeds were treated as in the experiments recorded in table III, except that at the end of seven days the seeds exposed to the gas from 0.010^{gm} of KCN or more per cubic foot were removed from the gas and placed in a gas free atmosphere.

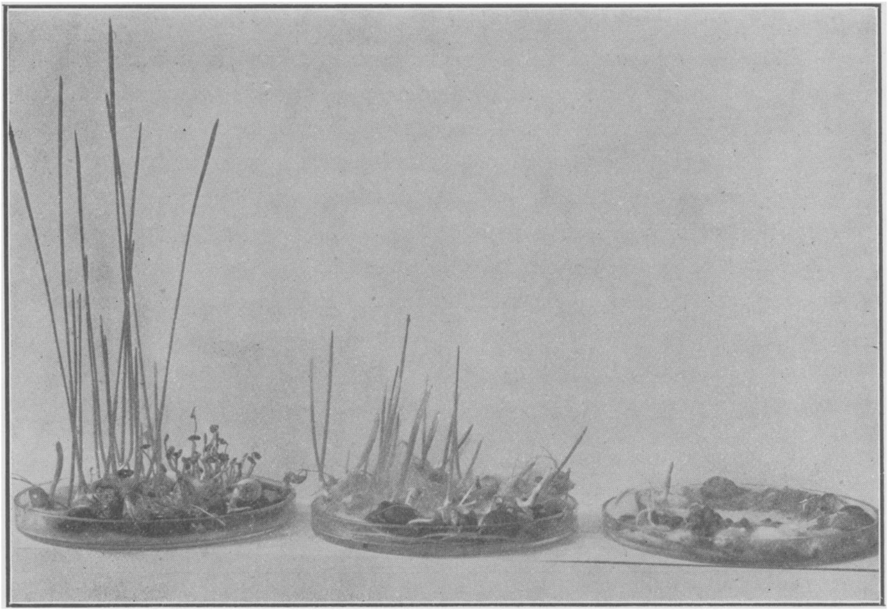

FIG. 5.—*a*, control; *b*, seeds were in gas from $.030^{gm}$ KCN per cubic foot for 168 hours; *c*, seeds were in gas from $.010^{gm}$ KCN per cubic foot for 168 days.—Photographed at end of 18 days. See table VI.

At the end of seven days, after placing the seeds in ordinary atmosphere, 50 per cent. of those that had been exposed to the gas from 0.010 of KCN germinated. In other words, the seeds that germinated had been held in a dormant condition for seven days in the gas and for seven days after removing from the gas, a total of fourteen days. Likewise seeds that had been in the gas from 0.050^{gm} of KCN per cubic foot were held in a dormant condition for twenty days. In the preceding case only five seeds out of every ten germinated, while in the latter instance only two seeds out of every ten germinated. Hence it should be noted that much depends upon the natural vitality of the seeds, not only in these experiments but in all cases where seeds are subjected to similar treatment. If the seeds were subjected for seven days to a charge of gas greater than that produced from 0.050^{gm} of KCN per cubic foot, they were unable to germinate in a single instance. In those cases where germination did take place, the subsequent growth of the seedlings was always slow and feeble. It is true that some of the seedlings, in these as well as in other experiments where the subsequent growth was slow, were able to overcome the influence of the gas after a longer or shorter time and to grow at the normal rate.

Since the seeds subjected to the gas from more than 0.050^{gm} of KCN per cubic foot were unable to germinate, it was decided to test the effect of a comparatively strong charge of the gas for a short time. The results of these experiments are recorded in table VII.

TABLE VII.

Same as table VI, except that a stronger charge of hydrocyanic acid gas was used for a short time.

Amt. of KCN per cubic foot	Time of soaking	Time of exposure to gas	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000 . .	24 hours	0	24 hours	100	normal
0.250 . .	24 "	3 hours	72 "	50	"
0.250 . .	24 "	6 "	no germination	0	....
0.250 . .	24 "	12 "	" "	0	....

In these experiments it was found that some of the seeds were able to resist for more than three hours the influence of the gas from 0.25^{gm} of KCN per cubic foot, although after three hours one half the seeds were unable to germinate and the other half were held in check for seventy-two hours or forty-eight hours beyond the usual time of germination. However, the seeds that did germinate produced seedlings that grew at the normal rate.

Seeds soaked, treated with gas, washed and placed in HCN-free atmosphere.—The experiments recorded in table VIII were undertaken in order to determine whether the hydrocyanic acid gas that retarded germination after the seeds were removed from the atmosphere of the gas remained in the moisture that adhered to the seeds, whether the gas was primarily absorbed by the seeds, or whether retardation was simply an after effect of the gas upon the seeds.

TABLE VIII.

Seeds soaked, placed for a definite time in hydrocyanic acid gas, then washed and placed in an atmosphere free from hydrocyanic acid gas; temperature throughout experiment about 18° C.

Amt. of KCN per cubic foot	Time of soaking	Time of exposure to gas	Subsequent treatment	Time required for germination	Percentage of germination	Subsequent growth of seedlings
0.000 .	24 hours	0	{ placed in pure air }	24 hours	100	normal
0.100 .	24 "	6 hours	washed	72 "	100	"
0.100 .	24 "	6 "	not washed	96 "	50	¾ nat. size
0.250 .	24 "	6 "	washed	144 "	100	normal
0.250 .	24 "	6 "	not washed	no germ.	0	....
0.250 .	24 "	18 "	washed	168 hours	60	½ nat. size
0.250 .	24 "	24 "	washed	240 "	10	slight
0.250 .	24 "	48 "	washed	no germ.	0	....

It is apparent that more or less of the hydrocyanic acid gas remains in the film of water that adheres to and surrounds the seeds after they are removed from the gas, since they germinate much more readily after washing. It should be noted that the washing did not consist in soaking the seeds but simply rinsing them under the hydrant. If the seeds were not washed they were unable to germinate after six hours in the gas from 0.250^{gm} of KCN per cubic foot, whereas the seeds were able to germinate after eighteen hours in the gas, providing they were washed immediately after removal. If they were exposed to the same charge of gas, viz., 0.250^{gm} of KCN per cubic feet for twenty-four hours or more, they were unable to germinate even when they were thoroughly washed after removing from the gas. It would seem from the experiments that more or less of this poisonous gas remains in the moisture that surrounds the seeds, and that the gas clings to the damp surface of exposed seeds. If the gas is not removed by washing it seems to have a strong affinity for moisture and for the seed, and eventually penetrates the seed even after the treated seeds have been exposed to the ordinary atmosphere. However, not all of the gas remains on the outer surface of the seed nor in the moisture sorrounding it, since a marked influence of the gas could be observed in those seeds that were first treated with the gas and then washed.

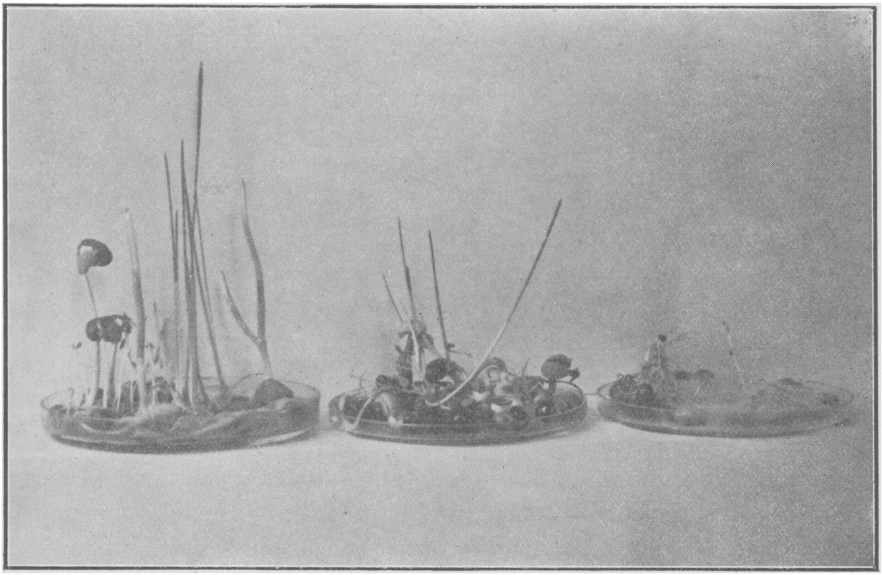

FIG. 6.—*a*, seeds in gas from 0.10^{gm} KCN per cubic foot for six hours, then washed and placed in gas-free atmosphere; growth practically normal; *b*, seed in gas from 0.25^{gm} KCN for eighteen hours, then washed and placed in gas-free atmosphere; *c*, seeds in gas from 0.25^{gm} KCN per cubic foot for twenty-four hours, then washed and placed in gas-free atmosphere.—Photographed at end of two weeks. See table VIII.

Conclusions.—Seeds, whether in the dry or moist condition, are capable of absorbing hydrocyanic acid gas from the surrounding atmosphere, whether the amount of gas in the atmosphere is large or small per cubic foot. The gas thus absorbed has a marked influence upon the germination of the seeds and upon the subsequent growth of the seedlings. This influence is exerted upon the embryo or upon the enzymes or upon the stored food material of the endosperm, or it may be that the gas exerts influence directly or indirectly upon two or more of these seed parts. If the grain or seeds are dry the influence of the gas is far less marked than if they are moist, and the drier they are the less the influence of the gas. It would seem that the gas exerts its influence, therefore, through the medium of the moisture contained in the seeds and in the seedlings. Even in older plants it is the more succulent parts that are most readily affected by the gas. The seed coats serve more or less as a protection to the inner seed parts, for as soon as the seedlings escape from the seed coats they are more seriously affected by the gas, and if the charge is sufficiently strong, the seedlings refuse to grow almost as soon as they leave the seed coats. Dry seeds are sufficiently resistant to the influence of hydrocyanic acid gas to be treated for several weeks with an atmosphere saturated with the gas without destroying their vitality. It would be impossible, however, to preserve even dry seeds indefinitely in any strength of the gas, since it eventually penetrates them and impairs and finally destroys their vitality. If the seeds are damp they are much more susceptible to the influence of the gas, and should not remain more than two or three hours in gas of sufficient strength to destroy animal life. If for any reason it becomes necessary for the damp seeds to remain for a longer time in the gas, the injury will be materially lessened by thoroughly washing the seeds in water as soon as they are removed.

The fact that damp seeds are more susceptible to hydrocyanic acid gas than dry seeds would indicate that the gas is taken up more readily by the damp seeds, and the same is true of other gases.

EFFECT OF HYDROCYANIC ACID GAS ON SEEDS FOR FOOD.

Dry seeds.—Only a few experiments have been performed along this line, but probably a sufficient number to determine the point in question, viz., whether dry seeds treated with hydrocyanic acid gas retain enough of the poison to make them injurious to animal life. Grain was subjected to gas of different strengths and for longer or shorter periods of time, varying from one to sixty days. Grains thus treated were from time to time fed to mice that had been caught without injury and placed in glass cages so that they could be observed constantly. The cages were provided with an abundant supply of air and water and kept at ordinary normal temperature of the laboratory where the mice had been living previous to the beginning of the experiment. Occasionally the mice began eating the grains as soon as they were placed within reach, but as a rule several minutes to several hours elapsed between the time the grains were taken from the hydrocyanic acid gas and the time they were eaten by the mice, thus giving time for any gas that remained in contact with the seed or that had penetrated the seed coat to escape into the atmosphere. In one instance, for example, a mouse was fed one dozen kernels of corn and three dozen grains of wheat that had been for four and one fourth days in an atmosphere containing gas from one gram of potassium cyanid per cubic foot. The mouse began eating the grain at once, and at the end of twenty-four hours had eaten the whole of five grains of corn and had eaten the chit out of five other grains. It had also eaten fourteen grains of wheat and had eaten the chit out of eleven others with no pathological results. Several similar experiments were carried through with like results. Hence it seems safe to conclude that dry grains treated for several days with hydrocyanic acid gas of sufficient strength to destroy insect pests that may be in the grain will in no way affect animal life, and may therefore be used for food without injury.

Damp seeds.—The damp seeds were soaked for twenty-four hours and then treated with gas in the same manner as in the preceding experiments, and were kept in the gas for different periods of time varying from several hours to several days. Here as in the germination experiments we find that moisture has a decided influence upon the susceptibility of the grains to the gas. For example: after some corn and wheat had been soaked for twenty-four hours in water and then left for forty-eight hours in the gas obtained from one gram of potassium cyanid per cubic foot, a mouse in apparently good health was given twelve grains of the corn and thirty-six grains of the wheat. The mouse began eating at once and ate the chit out of one kernel of corn and began on a second kernel when he suddenly became stupid and was unable to walk without staggering. That the mouse was hungry is evidenced by the fact that it began eating as soon as the grain was placed in the cage, and from the fact that it had been given but little food on the preceding day for the purpose of having it hungry enough to begin at once on the grain as soon as it should be removed from the gas. Although the mouse lived for several hours, it eventually died apparently from the effects of the small amount of grain eaten, as it did not eat any more of either kind of grain nor would it eat cheese or any other material placed before it. In general, it was found that if the mice ate the grain immediately after taking it from the gas they became stupid and eventually died from the effects. However, if the grain was allowed to remain for a time out of the gas before it was eaten, no ill effects seemed to be produced, although the grain did not seem to return to its normal condition, as it was never eaten readily even after it became perfectly dry. When the mice could be induced to eat it, as they were in several instances, it did not seem at all injurious. It may be concluded, therefore, that the fumigation of dry grains with hydrocyanic acid gas does not in any way injure the grain for food purpose. And even if the grain is damp it will not be injured for food if it is allowed to air for a short time after fumigating before it is prepared for use.

SUMMARY.

Dry seeds may be fumigated with the usual strength of hydrocyanic acid gas for the length of time required for the destruction of animal life without in any degree interfering with the germinating power of the seeds.

Dry seeds may be subjected for several months to the influence of hydrocyanic acid gas at the rate of one gram or less of potassium cyanid per cubic foot without entirely destroying the ability of the seeds to germinate.

Dry seeds subjected to the influence of hydrocyanic acid gas derived from one gram of potassium cyanid per cubic foot will lose their germinating power at the expiration of eight months, while the same seeds subjected to the gas from one third of a gram of potassium cyanid per cubic foot will retain their vitality until the expiration of twelve months.

The exposure of dry seeds for from fifteen to sixty days to the influence of hydrocyanic acid gas from one third to one gram of potassium cyanid per cubic foot will hasten germination and accelerate the growth of the resulting seedlings. Although the acceleration continues for several days, it does not seem to be of sufficient duration and degree to be of any practical value.

Damp seeds are much more sensitive to the influence of hydrocyanic acid gas than dry seeds.

Seeds soaked twenty-four hours or more will not germinate in gas stronger than 0.003^{gm} of potassium cyanid per cubic foot, whereas, if the seeds are soaked but twelve hours, they are able to germinate in an atmosphere containing hydrocyanic acid gas from 0.050^{mg} of potassium cyanid per cubic foot, and in much less time than when soaked for twenty-four hours.

Seeds soaked thirty-six hours will germinate much more readily than when soaked only twenty-four hours, but will not germinate in a stronger atmosphere of hydrocyanic acid gas than 0.003^{gm} of potassium cyanid per cubic foot.

Seeds soaked for twenty-four hours and then left for seven days in an atmosphere of hydrocyanic acid gas will remain inactive while in the gas, and from seven to twelve days after removal, but will eventually germinate to some extent if the strength of gas used does not exceed 0.050^{gm} of potassium cyanid per cubic foot, *i. e.*, hydrocyanic acid gas is capable of holding seeds in an inactive state for two weeks or longer without destroying their vitality, even when the conditions are otherwise favorable for germination.

Damp seeds are injured to a much less extent when fumigated with hydrocyanic acid gas if they are washed immediately after removing from the poisonous atmosphere.

The vitality of damp seeds is seriously injured if treated for three hours with gas from 0.25^{gm} of potassium cyanid per cubic foot, provided the seeds are not washed after removing from the influence of the gas. On the other hand, damp seeds may be treated with the same strength of gas for six hours with no appreciable injury, provided they are washed and placed in an atmosphere of ordinary air to germinate.

Dry seeds treated for several days with hydrocyanic acid gas of any strength will not be injured for food.

Damp seeds treated with hydrocyanic acid gas of any strength, and even for short periods of time, should not be used for food until several hours after removing from the gas. The effect of the gas eventually passes off and the grain may be eaten with safety, although long exposure to the gas seems to render it unpalatable. Grains and other seeds may be fumigated with hydrocyanic acid gas for the destruction of insect pests without injury to the germinating quality of the seeds and without rendering them injurious as foods.

AGRICULTURAL COLLEGE,
College Park, Md.